

1982, Delpizzo and Joyner 1987), an occupation that has been found to have an above average risk of adverse pregnancy outcomes (Kallen et al 1982).

More intriguing are the studies suggesting the possibility of hazards resulting from low-level environmental fields. From a public perception's view point, these may be roughly divided into two categories: general health surveys and cancer studies. The first group (for reviews see WHO 1981 and WHO 1993) have not established any clear evidence of adverse health effects, with the exception of some studies (Gordon 1966, Marha et al 1971, Dumanski et al 1975, Serdjuk 1977, Deroche 1971, Moscovici 1974) that reported an excess of some autonomic and central nervous system complaints and symptoms generally consistent with those of mild depression, that came to be collectively known as "microwave sickness". Because of the subjective nature of these symptoms, the reliability of these studies is difficult to assess. Moreover, most of these studies have not been reported in the mainstream scientific literature. The possibility of a true association between exposure to RF radiation and psycho-physiologic nervous system reaction cannot be ruled out. For epidemiology to fruitfully address this question, retrospective cohort studies need to be carefully designed to prevent recall bias.

Of much greater concern in the public eye is the claim that exposure to low levels of RF radiation may result in an increase in the incidence of at least some cancers (particularly leukemia and brain tumours). This rests on three elements:

- very few in vivo and in vitro studies
- some anecdotal evidence of brain tumors that because of their position and time of diagnosis were linked to the use of cellular telephones.
- a number of epidemiological studies that suggest an association between employment in occupation presumed to be exposed to above average electromagnetic radiation

With the exception of one study (Lester and Moore 1982), all epidemiological studies on RF exposure were conducted on occupationally exposed subjects. Lester and Moore (1982) reported an increase in cancer mortality in counties within which and Air Force base was located. Their finding was rejected by a subsequent analysis of the same data by Polson and Merritt (1985). Both of these studies have limited credibility. The ecological approach used by Lester and Moore is of intrinsically low quality and is fraught with dangers. Many other potentially relevant factors were not (and could not be) taken into proper

consideration. On the other hand, the type of *post-hoc* re-evaluation carried out by Polson and Merritt needs to be regarded cautiously, since it is open to the possibility of observer bias.

The studies on occupational EMR exposure have been the subjects of several reviews (WHO 1981, 1993). One of the most recent and complete evaluations was done by the Advisory group on Non-ionizing Radiation for the National Radiation Protection Board (NRPB) of Great Britain. With respect to occupational exposure, NRPB speculated that "the large number of observations relating to leukemia... may well be due to bias in favor of publishing results that suggest a hazard, rather than the reverse". However it regards the evidence of a brain cancer risk as "a little more consistent" and comments that "there is some to suggest that the excess increases with duration of employment". It concluded that "the evidence suggests that occupational exposure to EM fields may cause a hazard of brain cancer, but it is far from certain that it does". This statement, together with NRPB's statement that "animal studies conducted at frequencies above about 100 kHz have provided some evidence for effects on tumor incidence" may be seen as supporting the anecdotal evidence of brain tumors arising from the use of cellular phones. The NRPB Advisory Group Chairman, Sir Richard Doll was quoted as saying, that with regard to the possibility of a cancer risk above 100 kHz, "there is room for more doubt" (MW News March/April 1992, p 9).

While doubt cannot be entirely eradicated at this stage, it is hard to see how epidemiological results could support this view. The first difficulty a reviewer faces is that of determining which studies should be considered. Although some of the occupations used as markers for exposure may entail exposure to RF radiation, this has not been verified. In most cases, EMF exposure is limited to ELF electric and magnetic fields. Therefore it is reasonable to argue that studies on electronics and telecommunications employees are studies on ELF exposure and not RF exposure. In the following tables, summarizing cohort and case-control studies of occupational exposure, the likelihood of exposure to RF/ μ w radiation and to ELF fields are tentatively assessed for each occupational group. Of the groups for which RF exposure is likely, only radio amateur operators and military personnel have been associated with an increase in the cancer incidence (these groups have been marked ® in the tables). In a few studies (marked ß) the occupation description was broad enough that the possibility of some of the subjects being exposed cannot be ruled out. Nevertheless, it seems reasonable to

conclude that, to the extent that these studies carry any information, when placed into the wider picture, they seem to indicate that a possible association between ELF and cancer may have confounded the RF studies, but not vice-versa. It is also interesting to note that Thomas et al (1987) found that subjects exposed to RF radiation in jobs other than those involving design, manufacture, installation or maintenance of electronic or electrical equipment, did not have an elevated brain tumor risk. This argues against exposure to μw /RF radiation being the causal factor for the observed association, although stratification of samples that are already small may easily lead to observations that appear to be inconsistent, purely because of sampling variations.

Table 12.1 Occupational groups investigated in cohort studies

reference	Occupation	exposure to $\mu\text{W}/\text{RF}$	exposure to ELF	excess cancer
Olin et al 1985	Electrical engineers	?	?	no
Törnqvist et al 1986	Power linesmen and power station operator	unlikely	likely	yes
Juutilainen et al 1990	All electrical except indoor installations	unlikely	likely	yes
Juutilainen et al 1990	Electrical (indoor install.)	unlikely	?	yes
Wiklund et al 1981	Telephone operations	?	?	no
Lindsay et al 1991 ²	All electrical occupations	?	likely	no
McLaughlin et al 1987	Electricians and Electronics workers, welders, metalworkers	?	likely	no
Vägerö et al 1985	Manufacturers of telecommunication equipment	?	likely	no
Vägerö and Olin 1983	Electronic and electrical manufacture	?	likely	no
Milham 1988a,b	Amateur radio operator	likely ♦	likely	yes
Guberan et al 1989	Electricians	unlikely	likely	yes small
Guberan et al 1989	Electrical engineers,	unlikely	?	no
Blair et al 1985	Electricians	unlikely	?	no
Törnqvist et al 1991	All electrically related occupations	?	likely	no
Szmigielski 1994	Career military personnel	likely ♦	?	yes

²Unpublished, quoted in NRPB 1992.

Table 12.2 Occupational groups investigated in case-control studies

reference	Occupation	exposure to $\mu\text{w}/\text{RF}$	exposure to ELF	excess cancer
Lin et al 1985	Electrical and telephone company servicemen	unlikely	likely	yes
Lin et al 1985	Electricians; dispatcher; electrical, electronic, aerospace and telecommunication engineers	? \oplus	likely	yes
Stern et al 1986	Electricians	unlikely	likely	yes
Pearce et al 1989	Electrical work	unlikely	likely	yes
Loomis and Savitz 1990	Electrical occupations	unlikely	likely	yes
McDowall 1983	Electrical occupations	unlikely	likely	yes
Thomas et al 1987	Electrical or electronics	? \oplus	likely	yes
Speers et al 1988	Electrical and telephone company servicemen	unlikely	likely	?
Speers et al 1988	Electricians; dispatcher; electrical, electronic, aerospace and telecommunication engineers	? \oplus	likely	yes
Preston-Martin et al 1989	All electrical occupations	unlikely	likely	yes
Magnani et al 1987	Electrical engineering industry	unlikely	likely	no
Magnani et al 1987	Electrical and electronic workers	? \oplus	likely	yes
Lewis 1990	Electrical occupations	unlikely	likely	no
Loomis and Savitz 1993	Electrical occupations	unlikely	likely	yes

In summary, the epidemiological evidence of possible adverse health effects of electromagnetic fields specifically in the RF frequency band, as distinct from EMR in general and ELF fields in particular, is almost non-existent. The few associations between employment in the so called 'electrical/electronics occupations' and cancer may raise the hypothesis that exposure to $\mu\text{W}/\text{RF}$ radiation is associated with some cancers, but the evidence is so weak that it barely makes a case for additional research. Nevertheless, continuing public concern, the absence of good quality epidemiological studies that may allay this concern, the results of a few animal studies and, more importantly, the *in vitro* studies showing that biological processes are affected by RF fields at levels below those required for significant tissue heating, will ensure that future studies will be carried out. It is therefore important to identify the major methodological issues that need to be addressed to ensure that these studies may make a meaningful contribution to understanding this issue.

Criteria for future studies

The results of an epidemiological study may be affected by bias, misclassification of exposure or of endpoint and limited sample size.

Sample size considerations

Epidemiological studies, particularly observational studies are essentially exercises in statistics. Their results, whether suggesting the presence or the absence of an association, must be qualified by the possibility that they may simply represent a chance finding. Reporting an association when one does not truly exists is called a type I error, while reporting no association when one truly exists is termed a type II error. For a given sample size, reducing the possibility of one type of error increases the probability of the other type. Which course of action is more appropriate is a matter for debate. Scientists traditionally presume the null hypothesis (no effect) and are required to prove that a health effect exists; however, public health professionals err on the side of safety, and tend to take protective action. If studies are intended to reassure the public must have a low probability of type II errors. Unfortunately, the choice of significance tests is usually dictated by convention, rather than a case-by-case critical analysis. Usually, the level of significance is set at 0.05, two-sided and a confidence interval is calculated accordingly. This means that an association (usually

expressed as a relative risk) is accepted as significant only if it is estimated that there is no more than a 5% chance that the confidence interval does not include the true relative risk. This practice leads to study results falling into two distinct groups: significant and non-significant. This is appropriate in situations where decisions (for example, to use an experimental treatment) are to be made on the basis of the study result. However, this approach is not always suitable in epidemiological research. Only if the confidence interval contains values that lies near unity, can a study result argue against an effect (Ahlbom 1993). If the interval is large, encompassing elevated relative risks as well as unity, the result is merely uninformative.

In practice, many (probably most) studies fall well short of having both a high power and high significance level. As an example, consider a study of 250 cases and as many controls in which a subject is classified as 'exposed' if he is in the top 5% of the exposure range. Assume that we are interested in detecting whether being exposed entails a relative risk of at least 2 (ie, we regard a smaller relative risk as clinically non-important). If we require the study to be significant with a confidence level of 95% (two-sided), such a study has only a 50% chance of satisfy this requirement if the risk truly exists. Conversely, if one wanted to limit the probability of a false-negative result to no more than 10%, there would be only a 50% probability that the confidence interval included the true relative risk. The wisest approach would be to acknowledge the limit of such a study and settle for a confidence level of about 77% which gives the study a similar statistical power. Confidence level decisions need to be taken *a priori* and convincingly explained, if the study is to be credible.

Exposure measurement errors

Direct measurement of thousand of subjects for the whole exposure period is usually impossible. Exposure is usually inferred from a point-in-time measurement or even less direct methods as job descriptions and activity diaries. Consequently, exposure is inevitably affected by non-negligible measurement errors. When exposure is measured on a categorical scale, measurement errors may lead to misclassification of exposure. Measurement errors and misclassification may be differential (if they affect cases and controls differently) or non-differential. Provided that measurement errors are non-differential, they will not result in an artefactual association and in general will produce conservative risk estimates. Exposure measurement errors also reduce the

statistical power of the study (Quade et al 1980, Freedman et al 1990, Delpizzo & Borghesi 1993) and the dose response relationship (Dosemici et al 1990, Armstrong 1990, Delpizzo 1992).

It is difficult to determine a priori what are acceptable exposure measurement errors and it may be very costly and not very effective to attempt to reduce them. At this stage, when the most important aim is to establish reliably whether an association between exposure and cancer does exist, it would be advisable to use available resources to increase the sample size to counteract the loss of statistical power.

Confounding and Bias

The term "bias" may have different meanings in epidemiology. In this case, we use the term to indicate inaccurate inferences resulting from flaws in study design, data collection, analysis and interpretation, review and publication of results. A typical bias encountered in occupational studies is the so-called "healthy worker effect". Full time workers are less likely to suffer from a number of conditions that would prevent their participation in the workforce and of a number of conditions (eg, depression, alcoholism, poverty, homelessness) sometimes associated with unemployment; as a consequence, cancer mortality may be proportionally more common than in the rest of the population. "Confounding" can also have several meanings. In the present context, it indicates a situation in which a measure of the effect of an exposure on risk is distorted because of the association of another factor(s) that influence the outcome under study. It follows that a confounder is a factor that is associated with both the exposure and the outcome of interest. Both confounding and bias can result in the overestimate or underestimate of a true risk or even create an artefactual association.

Bias may be prevented by a careful study design. Confounding may not always be prevented, but may be controlled by stratified analysis, a technique requiring the subdivision of the sample. This underscores again the importance of a large sample size.

Study design

Normally, a case-control study is preferable for cancer studies, because, given the relative rarity of the endpoint, it is more efficient to select diseased subjects before exposure is assessed. The cohort design, in which subjects are initially selected on the basis of their exposure status, is the preferable option when exposure is uncommon.

No study design is ideally suited to this situation, since both the endpoint of interest and the exposure are rare. However, given the obvious difficulties of exposure assessment, a cohort design appears to be the lesser of the two evils.

Since exposure to above-average RF fields is often accompanied by above-average exposure to ELF fields, identifying cohorts for which this is not the case is of paramount importance. Thus, feasibility studies with this aim should receive the first priority. Suggested possibilities are military personnel, RF plastic welders and diathermy operators. Electronics and telecommunication workers, for whom elevated ELF exposure have been observed (Bowman et al 1988) are not suitable subjects.

In summary, if epidemiology is to provide any insight into the question of RF exposure and cancer, very large studies will need to be carried out. Given Australia's small population and limited resources, this may be difficult to accomplish. The possibility of international coordinated research should be given consideration.

CSIRO EMR REPORT

GLOSSARY

- Absorption** In radio wave propagation, attenuation of a radio wave due to its energy being dissipated, i.e., converted into another form, such as heat.
- Ambient** Encompassing or surrounding area.
- Antenna regions** The distinction between electromagnetic fields far from, and those near to, the antenna. The regions are usually classified into three zones: near (static) zone, intermediate (induction) zone and far zone, located by drawing spheres of different radii around the antenna. The radii are approximately $r < l$ for the near zone, $r = l$ for the intermediate zone, and $r > l$ for the far zone. Note that l is the wavelength of the electromagnetic field produced by the antenna. In the far zone, field components (E and H) lie transverse to the direction of the propagation, and the shape of the field pattern is independent of the radius at which it is taken. In the near and intermediate zones, the field patterns are quite complicated, and the shape is, in general, a function of the radius and angular position (azimuth and elevation) in front of the antenna.
- Antenna** The part of a radio system that is designed to radiate electromagnetic waves into free space (or to receive them). This does not include the transmission lines or waveguide to the radiator.
- Antigen** Something the immune system recognises as foreign. An antigenic determinant is the small part, of a larger foreign target, which is actually recognised.
- Athermal effect (nonthermal effect)** Any effect of electromagnetic energy on a body that is not a heat-related effect.
- ATP (adenosine triphosphate)** A molecule used as a temporary energy store by cells. Energy is harnessed by the hydrolysis of a phosphate group, producing ADP (adenosine diphosphate) as a product.
- Attenuation** The progressive diminution in space of certain quantities characteristic of a propagation phenomenon.
- Behaviour** In animals, learning is a long-lasting change that results from experience with environmental events and includes actions such as solving a maze for food. Spontaneous behaviours are actions that do not result from a response to direct stimulation and include behaviours like locomotor activity.
- Biophysical mechanisms** Physical and/or chemical interactions of electric and magnetic fields with biological systems.
- Blood-brain barrier** A functional concept to explain the observation that many substances transported by blood readily enter other tissues, but do not enter the brain. The barrier functions as if it were a continuous membrane lining the brain vasculature.

Calcium efflux The release of calcium ions from a sample into a surrounding solution.

cAMP A second-messenger often used in cells to transfer signals from a surface receptor to other parts of the cell.

Cancer Any malignant, cellular tumour. The term cancer encompasses a group of neoplastic diseases in which there is a transformation of normal body cells into malignant cells. This probably involves some change in the genetic material, DNA, as a result of faulty repair of damage to the cell caused by carcinogenic agents or ionizing radiation. The altered cells pass on inappropriate genetic information to their progeny cells and begin to proliferate in an abnormal and destructive way.

Carcinogen A chemical, biological, or physical agent capable of producing tumor growth.

Carcinogenic process A series of stages at the cellular level culminating in the development of cancer.

Chromosome A very long molecule of DNA, complexed with protein, containing genetic information.

Circularly polarized If the electric field is viewed as a point in space, the locus of the end point of the vector will rotate and trace out an ellipse, once each cycle.

Clastogenic effects Microscopically visible damage or changes to chromosomes. (Truncation, translocation, deletions, sister chromatid exchange, change in chromosome number, etc.)

Clone of cells A group of cells all derived from (and genetically identical to) a single parent cell, by the process of clonal expansion.

Continuous wave A wave whose successive oscillations are, under steady-state conditions, identical.

Controlled environment Controlled environments are locations where there is exposure that may be incurred by persons who are aware of the potential for exposure as a concomitant of employment, or by other cognizant persons.

Current The flow of electric charge.

Cycle The complete range of states or values through which a phenomenon or periodic function passes before repeating itself identically.

Cytotoxicity Toxic effects in cells.

Developmental effects Effects in the developing offspring due to exposure before conception (either parent), prenatally, or postnatally to the time of sexual maturation. Developmental effects may be expressed at any time in the life span of the organism. Developmental effects are a subset of reproductive effects.

DNA Deoxyribonucleic acid. The nucleic acid molecule in chromosomes that contains the genetic information.

Dosimetry The measurement or the determination by calculations of the internal electric field strength or induced current density, or of the specific absorption (SA) or

specific absorption rate (SAR) distributions, in humans or animals exposed to electromagnetic fields and waves.

Electric dipole Two separated electric charges; a molecule (or other structure) having the effective centres of positive and negative charges separated.

Electromagnetic energy The energy stored in an electromagnetic field.

Electromagnetic wave A wave characterized by variation of the electric and magnetic fields.

Electrophoresis A technique used to separate molecules, normally according to size.

Embryo The early stages in the developing organism in which organs and organ systems are developing. For humans, this stage lasts between the second through eighth week after conception.

Endpoint An observable or measurable biological, chemical, or functional event used as an index of the effect of a chemical, physical, or biological agent on a cell, tissue, organ, organism, etc.

Energy density (electromagnetic field) The electromagnetic energy contained in an infinitesimal volume divided by that volume.

Enzyme A protein whose function is that of a catalyst, e.g. lytic and lysosomal enzymes damage cell membranes and degrade cell debris, respectively.

Epidemiology The study of the occurrence and distribution of a disease or physiological condition in human populations and of the factors that influence this distribution.

Epigenetic Non-genetic

Erythrocyte A red blood cell, or corpuscle. One for the formed elements in peripheral blood. In most mammals mature erythrocytes are biconcave discs that have no nuclei. The cell consists mainly of haemoglobin. Erythrocyte formation takes place in the red bone marrow in the adult and in the liver spleen and bone marrow in the fetus.

Eukaryote An organism with a defined nucleus, organelles (mitochondria, etc.) and more complex genetic mechanisms in its cells (e.g. yeast or animal cells) (of prokaryote).

Exposure Exposure occurs whenever and wherever a person is subjected to electric, magnetic or electromagnetic fields or to contact currents other than those originating from physiological processes in the body and other natural phenomena.

Exposure, long-term This term indicates exposure during a major part of the lifetime of the biological system involved; it may, therefore, vary from a few weeks to many years in duration.

Exposure, partial-body Partial-body exposure results when RF fields are substantially nonuniform over the body. Fields that are nonuniform over volumes comparable to the human body may occur due to highly directional sources, standing-waves, re-radiating sources or in the near field. See RF "Hot-spot".

- Extrapolation** An estimate of response or quantity at a point outside the range of the experimental data. Also refers to the estimation of a measured response in a different species or by a different route than that used in the experimental study of interest (i.e., species-to-species, route-to-route, acute-to-chronic, high-to-low).
- Far field region** That region of the field of an antenna where the angular field distribution is essentially independent of the distance from the antenna. In this region (also called the free space region), the field has a predominately plane-wave character, i.e., locally uniform distributions of electric field strength and magnetic field strength in planes transverse to the direction of propagation.
- Fibroblast** Cells of spindle or irregular shape responsible for fibre formation.
- Frequency** The number of complete cycles of a periodic waveform per unit time. Frequency is expressed in Hertz (Hz), which is equivalent to one cycle per second.
- Gene** The simplest complete functional unit in a DNA molecule. A linear sequence of nucleotides in DNA that is needed to synthesize a protein and/or regulate cell function.
- Genotype** The genetic constitution of an individual or a cell (of phenotype) proteins with sugar (carbohydrate) groups attached, often involved in recognition or signalling mechanisms.
- Gigahertz (GHz)** One billion (1,000,000,000) hertz.
- Glioma** A tumour composed of neuroglia in any of its states of development; sometimes extended to include all intrinsic neoplasms of the brain and spinal cord.
- Growth factor** A substance which stimulates a cell to grow and divide.
- Hertz (Hz)** One cycle per second.
- Hormone** A chemical substance, formed in one organ or part of the body and carried in the blood to another organ or part where it alters the functional activity, and sometimes the structure, of one or more organs in a specific manner.
- Hyperthermia** The condition of a temperature-regulating animal when the core temperature is more than one standard deviation above the mean core temperature of the species in resting conditions in a thermoneutral environment.
- Immune system** The body's primary defense against abnormal growth of cells (i.e., tumours) and infectious agents such as bacteria, viruses, and parasites.
- In utero** In the uterus; unborn.
- In vitro** Literally means "in glass", isolated from the living organism and artificially maintained, as in a test tube or culture dish.
- In vivo** Occurring within the whole living body.
- Inositol phosphate pathway** An internal cell signalling pathway, involving the substrate inositol phosphate, with a role in controlling the cell cycle.
- Ion channel (gate)** A protein which allows the passage of ions across a membrane.

- Ion efflux** The movement of ions, charged atoms or molecules, from a sample into a surrounding solution.
- Latency** The time between exposure to an injurious agent and the manifestation of a response.
- Leukemia** A progressive, malignant disease of the blood-forming tissues, marked by an excessive number of white blood cells and their precursors.
- Ligand** A specific molecule which binds to a receptor, usually with high affinity.
- Liposome** A spherical structure, usually multilamellate, prepared from eukaryotic cell membranes which may be used as a carrier for glycoprotein antigens and drugs.
- Lymphocyte** A cell of the immune system. The two subsets, T and B-cells, kill foreign cells and produce antibodies, respectively.
- Lymphoma** Any abnormal growth (neoplasm) of the lymphoid tissues. Lymphoma usually refers to a malignant growth and thus is a cancer.
- Lysis** Dissolution or destruction of cells.
- Malformation** A permanent structural change in a developing organism that may adversely affect survival, development, or function.
- Malignant** Harmful, virulent, life-threatening.
- Maximum permissible exposure (MPE)** The rms and peak electric and magnetic field strengths, their squares, or the plane-wave equivalent power densities associated with these fields and the induced and contact currents to which a person may be exposed without harmful effect and with an acceptable safety factor.
- Megahertz (MHz)** One million (1,000,000) hertz.
- Metabolism** The biochemical reactions by which energy is made available for the use of an organism from the time a nutrient substance enters, until it has been utilized and the waste products eliminated.
- Metastasis** A process where cells break away from a tumour and spread around the body (verb: metastasise).
- Microwaves** Electromagnetic waves of sufficiently short wavelength that practical use can be made of waveguide and associated cavity techniques in their transmission and reception. Note: the term is taken to signify waves having a frequency range of 300 MHz-300 GHz.
- Mitochondrion** A cellular organelle in which respiration occurs.
- Mitogen** An agent which can induce cells to enter mitosis (to divide).
- Mitosis** Cellular and nuclear division that involves duplication of the chromosomes of a parent cell and formation of two daughter cells.
- Model** (1) Mathematical model. A mathematical representation of a natural system intended to mimic the behaviour of the real system, allowing description of empirical data, and predictions about untested states of the system. (2)

Biological model. A condition or disease in animals similar to the condition or disease in human beings.

Modulation The process of varying the amplitude, frequency, or phase of an RF carrier wave.

Morphology The appearance and structure of an organism or cell. Cells may be described by their morphology or their biochemistry. (adjective: morphological).

mRNA (messenger RNA) An RNA copy of the genetic code for a given gene, used as a template in protein synthesis. Also known as poly-A RNA in eukaryotic cells due to a "tail" of "A" nucleotides attached to the end to aid stability, transport etc.

Mutagen An agent which can induce mutation.

Mutagenesis The process of creating mutations.

Mutation A stable, heritable change in the DNA sequence at a specific site in the genome of an organism. This constitutes a change in the genotype and, if expressed, may alter the phenotype.

Near-field region A region generally in proximity to an antenna or other radiating structure, in which the electric and magnetic fields do not have a substantially plane-wave character, but vary considerably from point to point. The near-field region is further subdivided into the reactive near-field region, which is closest to the radiating structure and that contains most or nearly all of the stored energy, and the radiating near-field region where the radiation field predominates over the reactive field, but lacks substantial plane-wave character and is complicated in structure.

Neurotransmitter A chemical substance that transmits nerve impulses across the space between nerve endings called the synapse.

Neutrophil A white blood cell with important roles in the immune and inflammatory systems.

Nonionizing radiation (NIR) Non-ionizing electromagnetic radiation incorporates all radiations and fields of the electromagnetic spectrum that do not normally have enough energy to produce ionization in matter. NIRs have an energy per photon less than about 12eV, wavelengths longer than 100 nm, and frequencies lower than 300 THz.

Oncogene A mutation of a naturally occurring gene involved in growth regulation that results in uncontrolled growth. Oncogenes are associated with the development of some forms of cancer.

Overexpression The abnormally high production of protein from a gene (of amplification).

Phenotype (ic) The physical constitution or description of an individual (or a cell) (of genotype).

Plasma membrane The membrane surrounding animal and plant cells.

- Plasmids** Independent circles of DNA, used by some bacteria to spread antibiotic resistance genes and by biologists to insert foreign genes into cells.
- Power (surface) density** Radiant power incident on a small sphere, divided by the cross-sectional area of that sphere.
- Power flux density** In radio wave propagation, the power crossing unit area normal to the direction of wave propagation. Symbol: W Unit: watts per square metre (W/m^2).
- Power** The time rate at which work is done. Electrical power is proportional to the product of current and voltage.
- Proliferation** an increase in cell or organism numbers.
- Promotion** The second hypothesized stage in a multistage process of cancer development. The conversion of initiated cells into tumorigenic cells.
- Protein kinases** A group of enzymes which regulate the activity of proteins by phosphorylating them.
- Proteinases** Enzymes which specifically degrade certain proteins.
- Pulse amplitude** The peak value of a pulse.
- Pulse duration** The interval of time between the first and last instant at which the instantaneous value of a pulse (or of its envelope if a carrier frequency pulse is concerned) reaches a specified fraction of the peak amplitude.
- Pulse modulated field** An electromagnetic field produced by the amplitude modulation of a continuous wave carrier by one or more pulses.
- Pulse output power** The ratio of (1) the average output power to (2) the pulse duty factor.
- Pulse repetition rate** The average number of pulses in unit time during a specified period.
- Radiofrequency (RF)** Any frequency at which electromagnetic radiation is useful for telecommunication. Note: in this publication the terms RF and microwave are interchangeable and refer to the frequency range 300 HZ-300 GHz.
- Reproductive effects** Effects on reproduction which may include, but not be limited to, alterations in sexual behaviour, onset of puberty, fertility, gestation, parturition, lactation, pregnancy outcomes, premature reproductive senescence, or modifications in other functions that are dependent on the integrity of the reproductive system. Developmental effects are a subset of reproductive effects.
- Resonance** The change in amplitude as the frequency of the wave approaches or coincides with a natural frequency of the medium. The whole-body absorption of electromagnetic waves presents its highest value, i.e., the resonance, for frequencies (in MHz) corresponding approximately to $114/L$, where L is the height of the individual in metres.
- RF "hot spot"** A highly localised area of relatively more intense radio-frequency radiation that manifests itself in two principal ways:

(1) The presence of intense electric or magnetic fields immediately adjacent to conductive objects that are immersed in lower intensity ambient fields (often referred to as re-radiation), and

(2) Localised areas, not necessarily immediately close to conductive objects, in which there exists a concentration of radio-frequency fields caused by reflections and/or narrow beams produced by high-gain radiating antennas or other highly directional sources. In both cases, the fields are characterised by very rapid changes in field strength with distance. RF hot spots are normally associated with very nonuniform exposure of the body (partial body exposure). This is not to be confused with an actual thermal hot spot within the absorbing body.

RNA Ribonucleic acid. Messenger RNA, the nucleic acid in cells that is the template for the sequential ordering of amino acids during protein synthesis, is synthesized in the nucleus of the cell during the process of transcription.

Specific absorption (SA) The energy absorbed per unit mass of biological tissue, expressed in joules per kilogram (J/kg). SA is defined as the quotient of the incremental energy absorbed by, or dissipated in, an incremental mass contained in a volume element of a given density. SA is the time integral of specific absorption rate (SAR).

Specific absorption rate (SAR) The rate at which energy is absorbed in body tissues, in watts per kilogram (W/kg). SAR is defined as the time derivation of the incremental energy absorbed by, or dissipated in, an incremental mass contained in a volume element of a given density. SAR is the dosimetric measure that has been widely adopted at frequencies above about 100 kHz.

Static fields Electric and magnetic fields that do not vary in intensity or strength with time.

Temperature regulation The maintenance of the temperature or temperatures of a body within a restricted range, under conditions involving variable, internal and/or external heat loads. Biologically, the existence of some degree of body temperature regulation by autonomic or behavioural means.

Thermal effect In the biological tissue or system, an effect that is related to heating of the tissue through the application of electromagnetic fields, and that can occur through other forms of heating.

Thermogenic levels Power densities of RF that produce a measurable temperature increase in the exposed object.

³H-thymidine A radiolabelled nucleoside used to quantitatively follow the synthesis/replication of DNA.

Time-varying fields Electric and magnetic fields that change in intensity or strength with time. Examples include 60 Hz, modulated, and transient fields.

Transcription The cellular process in which messenger RNA is synthesized, i.e., the process in which the genetic information in DNA is copied.

Transformation The genetic alteration of a cell so that it will form a tumour if injected into a suitable host animal. Transformed cells also exhibit characteristic growth changes in culture (cf immortalisation).

Translation The assembly of amino acids into a protein, using the information in RNA.

Tumour A swelling caused by the uncontrolled growth of cells.

Tumour suppressor gene A normal cellular gene involved in regulating cell behaviour. Mutations can contribute to cancer in a recessive fashion.

Tumour Swelling, one of the cardinal signs of inflammation; morbid enlargement. Tumours are also called neoplasms, which means that they are composed of new and actively growing tissue. Their growth is faster than that of normal tissue, continuing after cessation of the stimuli that evoked the growth.

Uncontrolled environment Uncontrolled environments are locations where there is the exposure of individuals who have no knowledge or control of their exposure.

Wavelength The distance between two successive points of a periodic wave in the direction of propagation, in which the oscillation has the same phase. Symbol λ
Unit: metre (m).

Whole-body exposure Pertains to the case in which the entire body is exposed to the incident electromagnetic energy or the case in which the cross section (physical area) of the body is smaller than the cross section of the incident radiation beam.

"Windowed" responses Effects found within bands or ranges of frequency or intensity separated by bands or ranges without effect; nonlinear exposure-response relations.

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